

# **EXHIBIT B**

(12) **United States Patent**  
**Cao**

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(54) **LIGHT SOURCE USING SEMICONDUCTOR DEVICES MOUNTED ON A HEAT SINK**

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This patent is subject to a terminal disclaimer.

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(52) **U.S. Cl.** ..... **362/294; 362/800; 362/545; 362/373; 362/547; 362/230**

(58) **Field of Search** ..... **362/800, 545, 362/294, 373, 547, 230**

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*Primary Examiner*—Sandra O'Shea

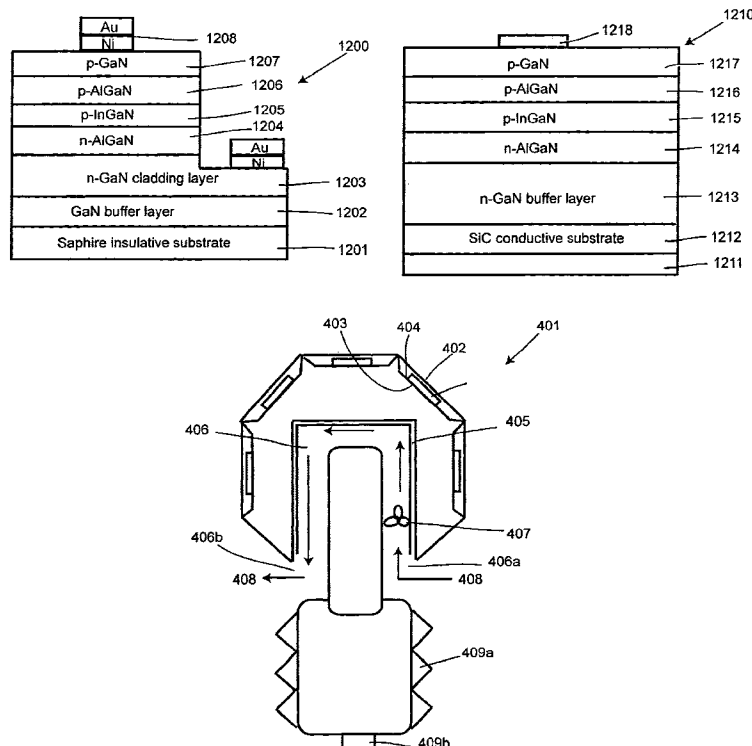
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(57) **ABSTRACT**

A semiconductor light source for illuminating a physical space has been invented. In various embodiments of the invention, a semiconductor such as and LED chip, laser chip, LED chip array, laser array, an array of chips, or a VCSEL chip is mounted on a heat sink. The heat sink may have multiple panels for mounting chips in various orientations. The chips may be mounted directly to a primary heat sink which is in turn mounted to a multi-panel secondary heat sink. A TE cooler and air circulation may be provided to enhance heat dissipation. An AC/DC converter may be included in the light source fitting.

**17 Claims, 16 Drawing Sheets**



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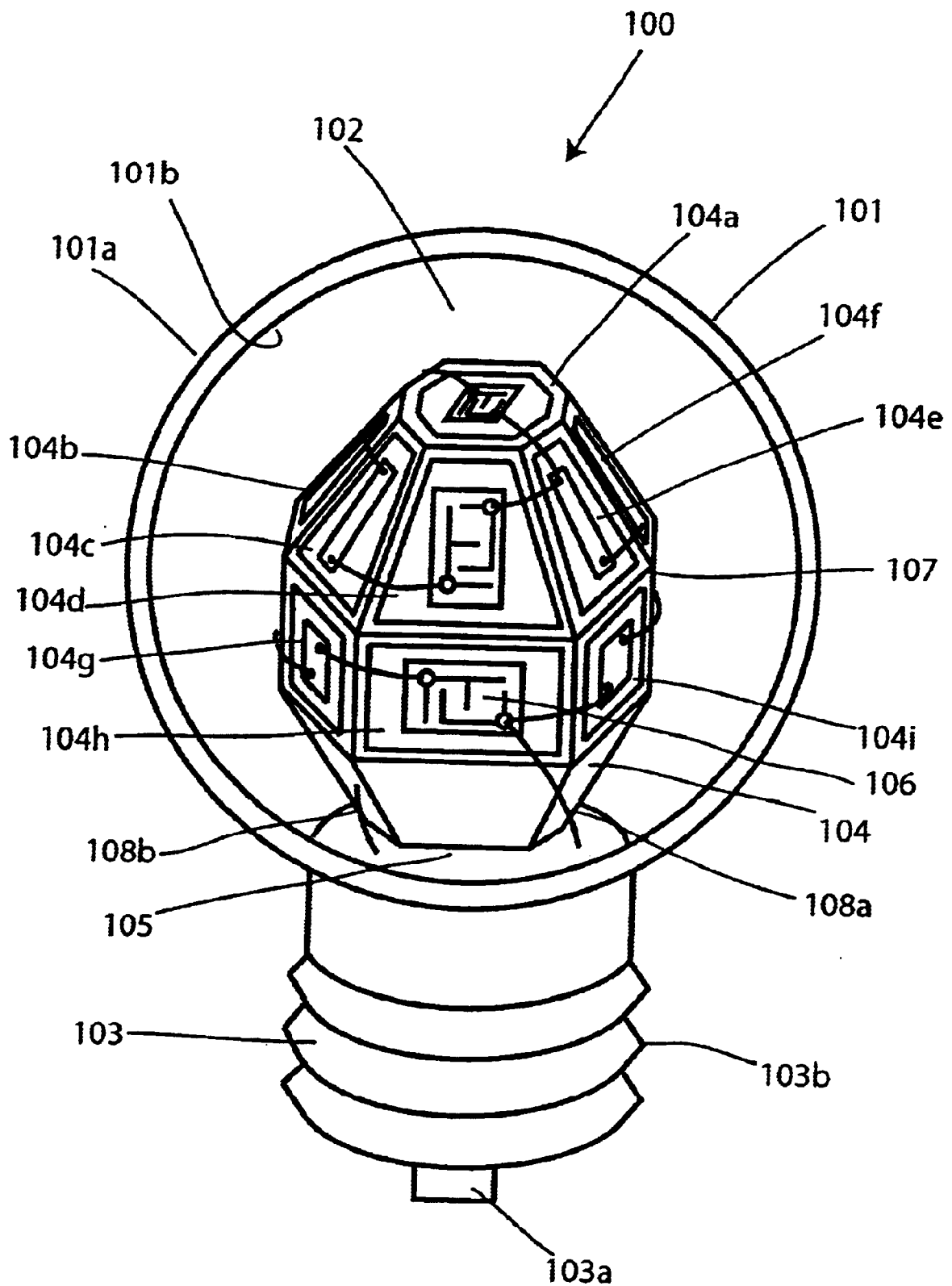


Fig. 1

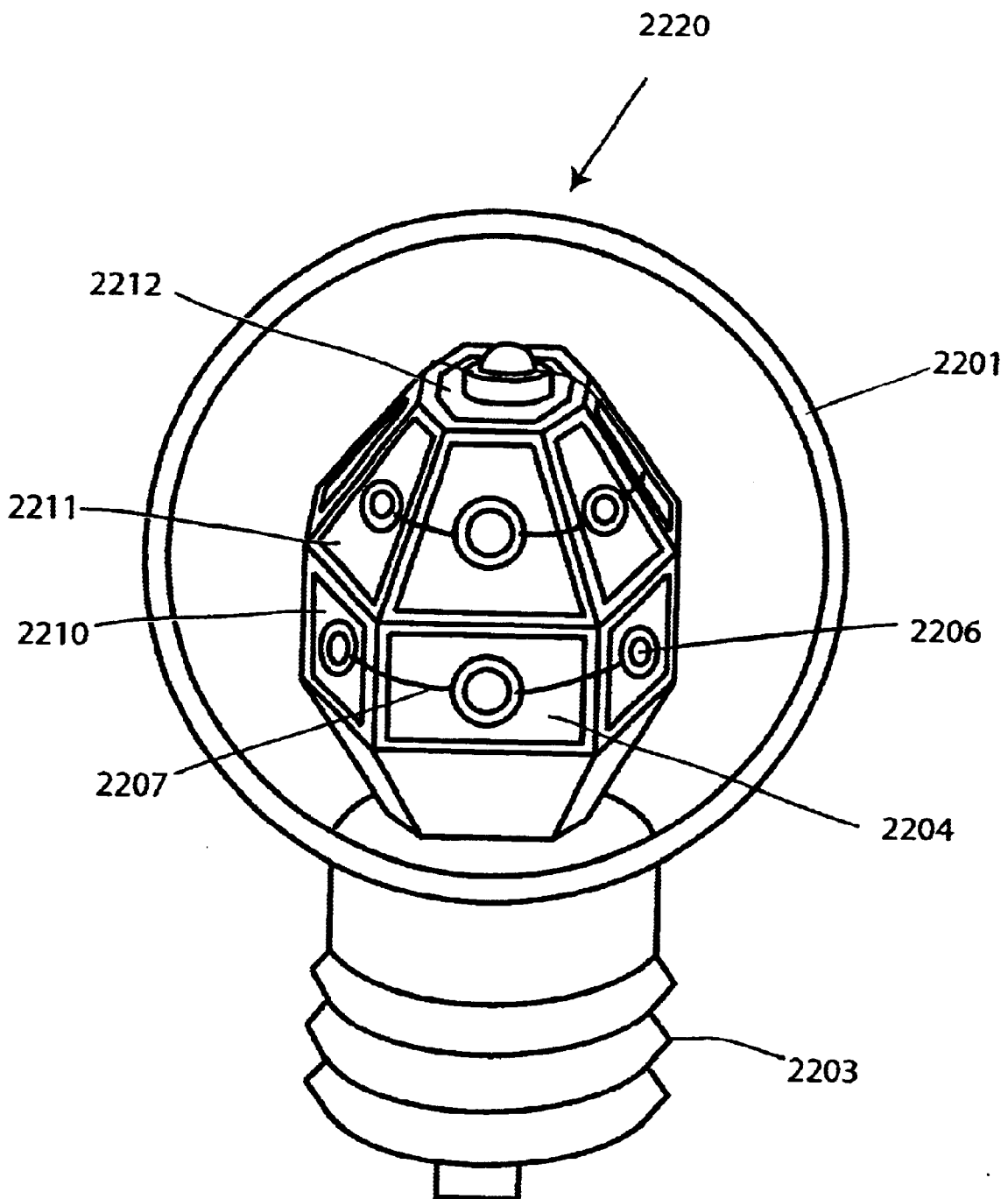


Fig. 2

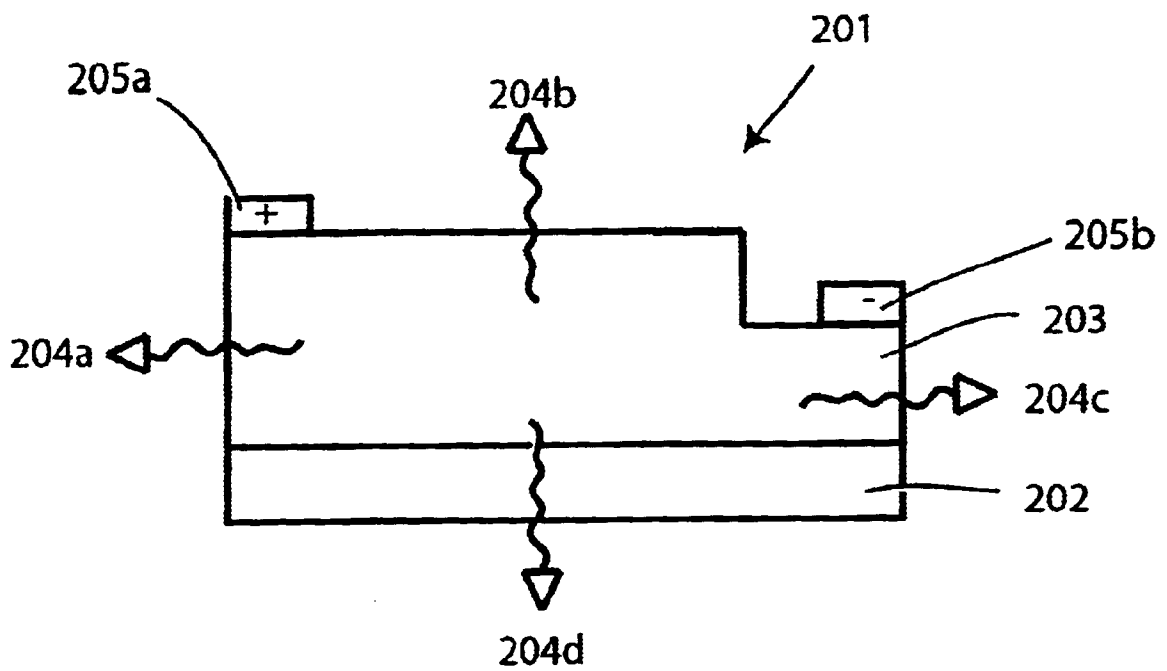


Fig. 3a

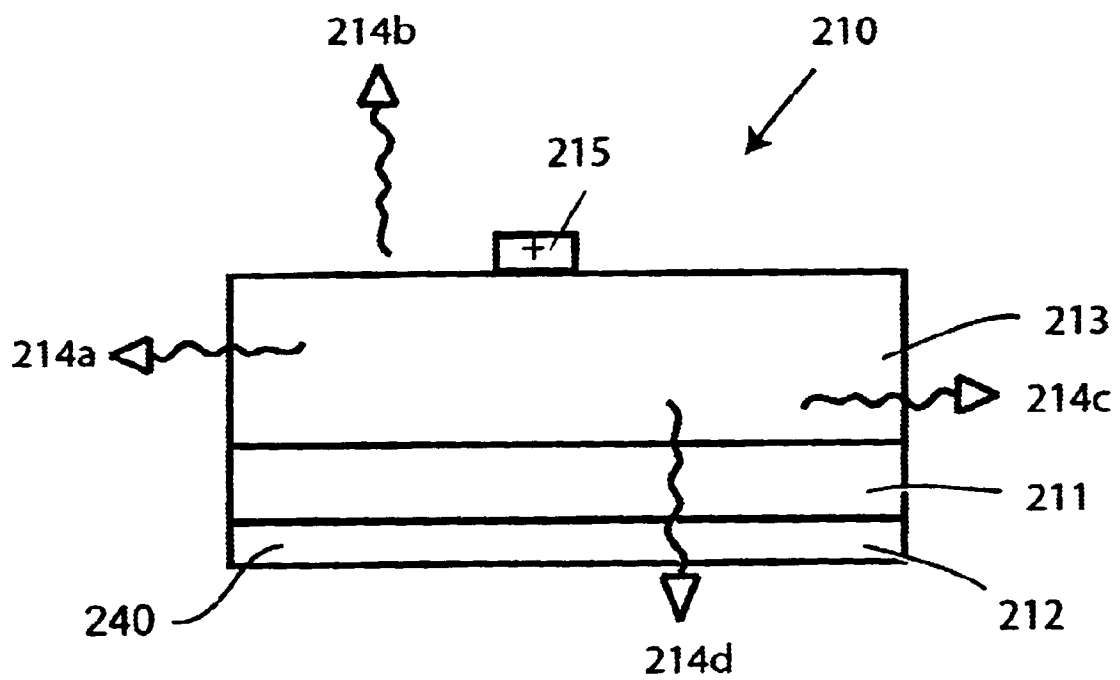


Fig. 3c

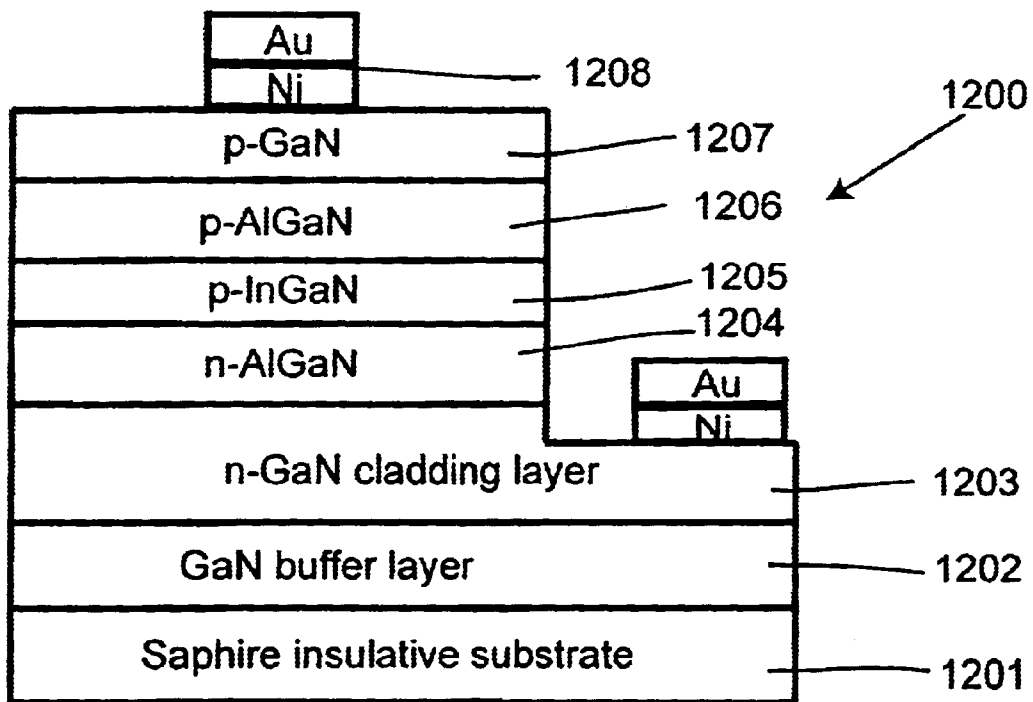


Fig. 3b

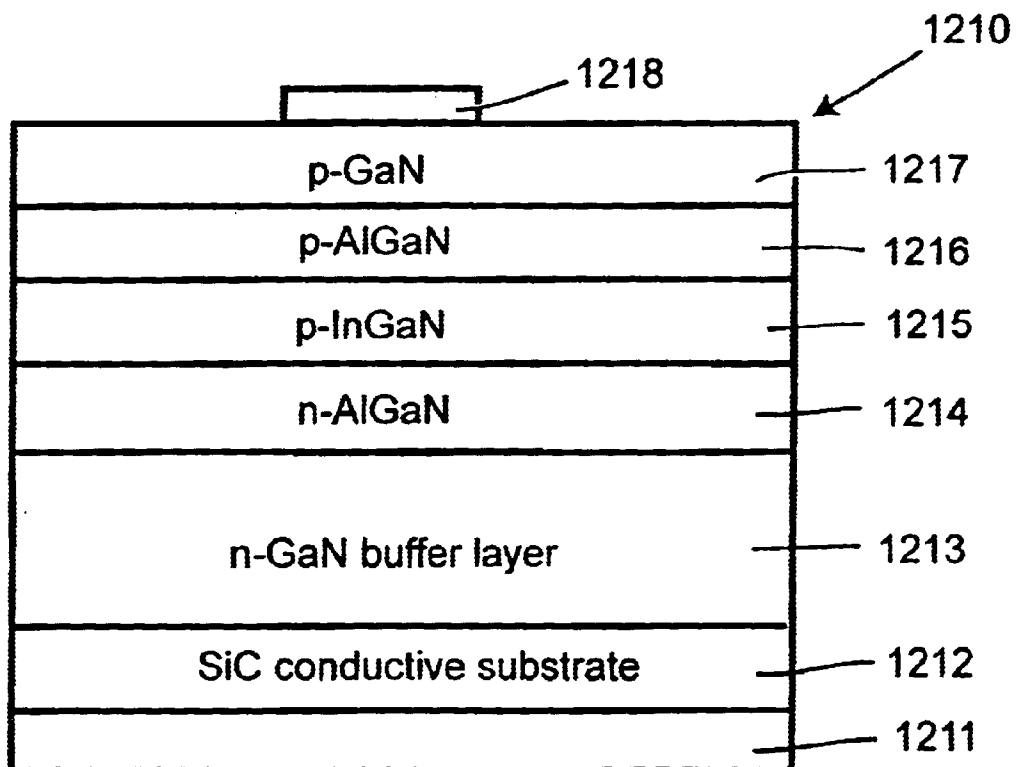


Fig. 3d

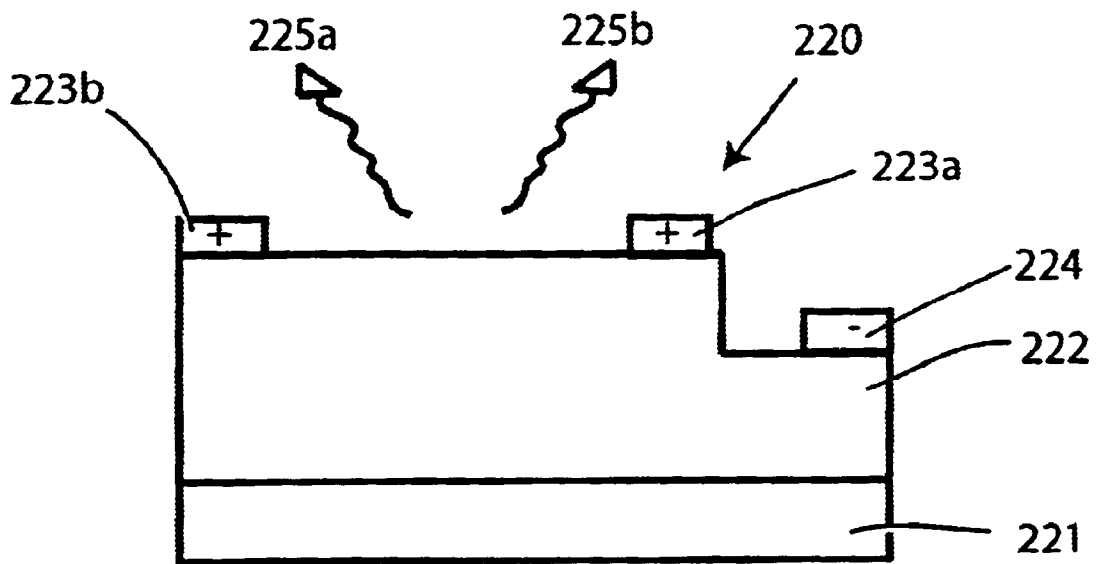


Fig. 3e

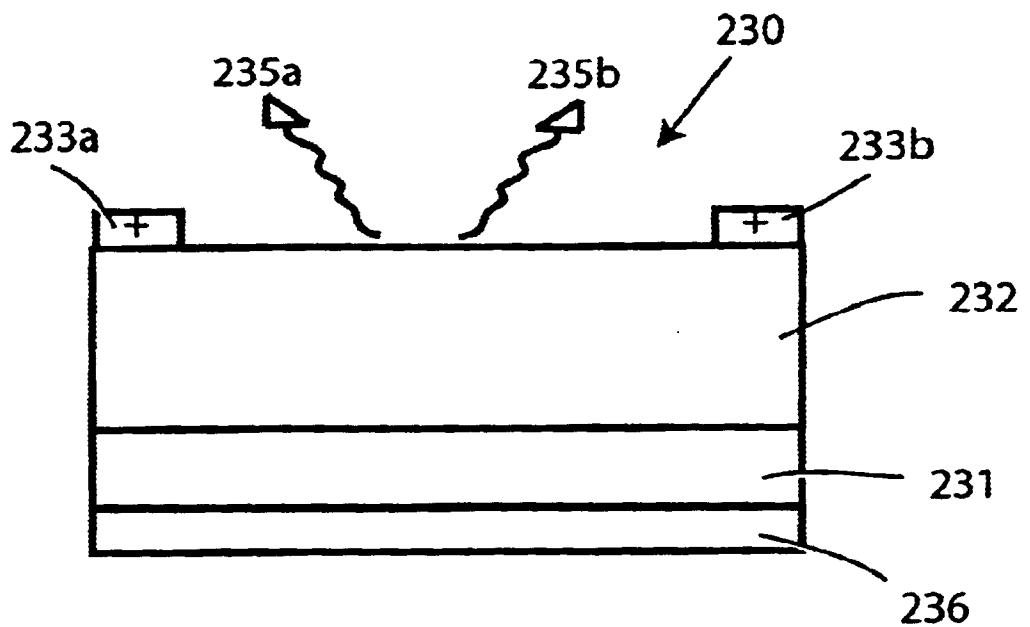
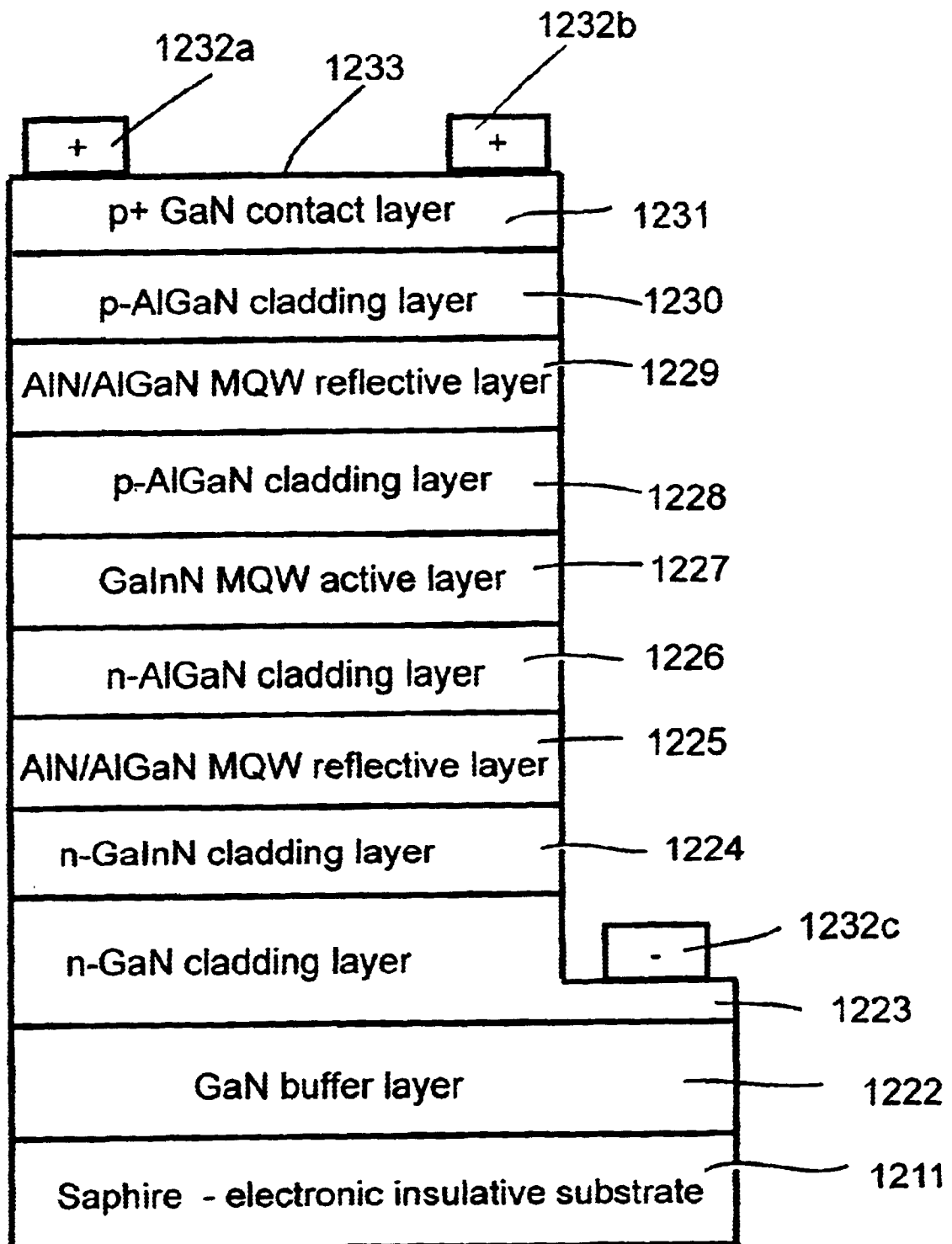


Fig. 3g

**Fig. 3f**



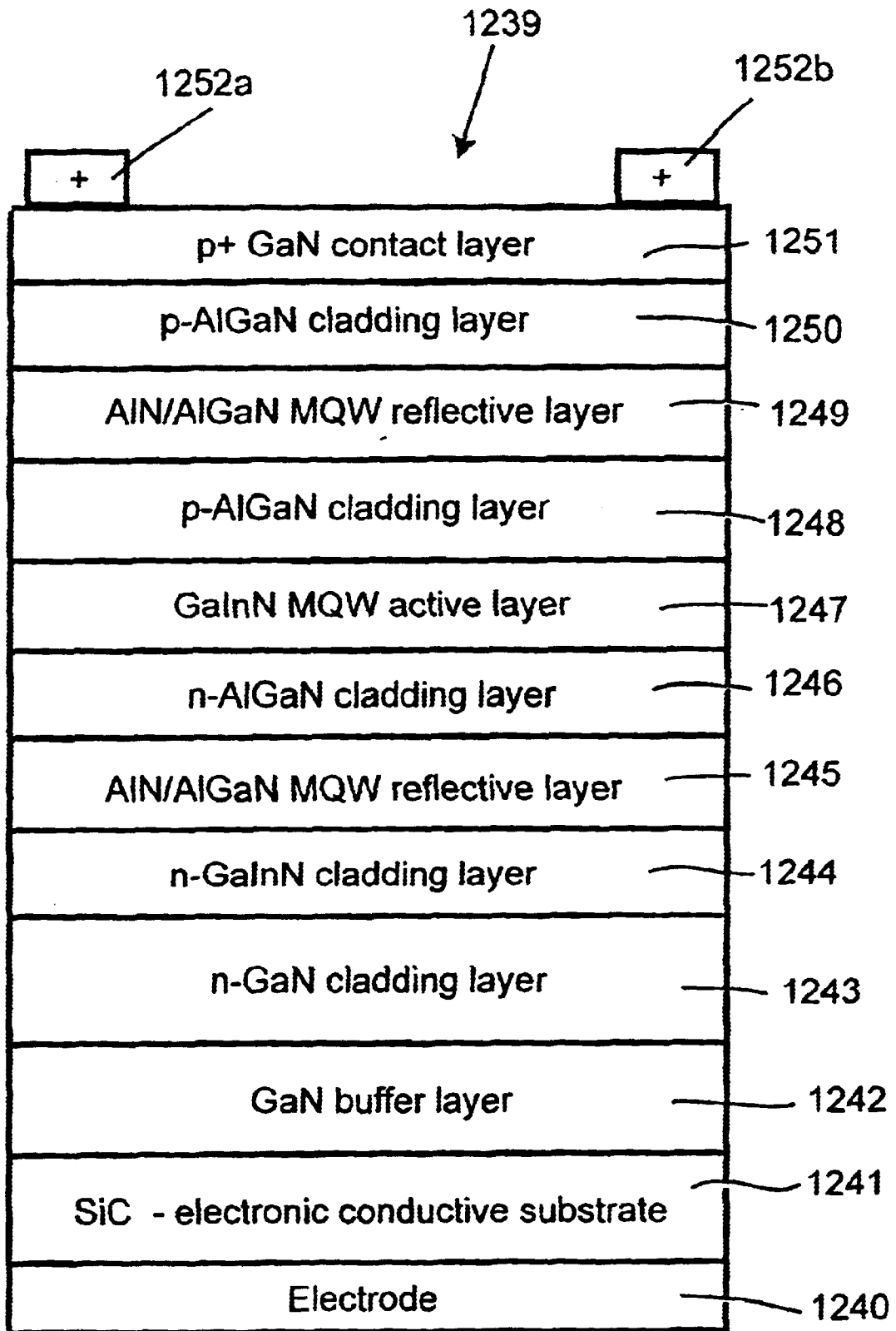


Fig. 3h

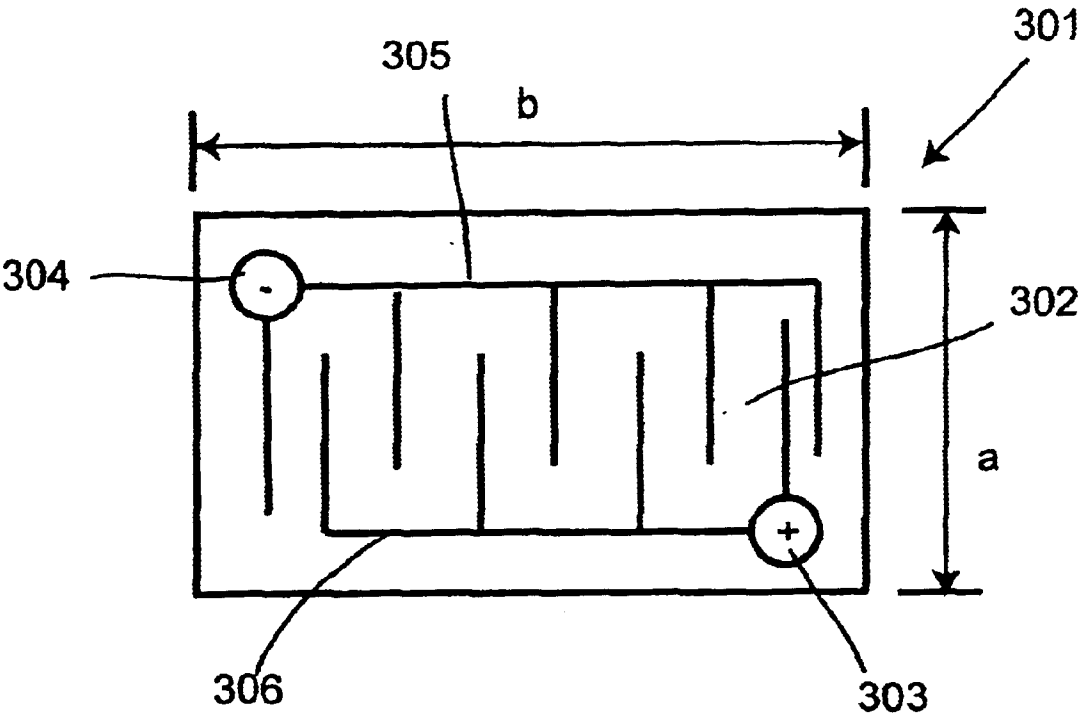


Fig. 4a

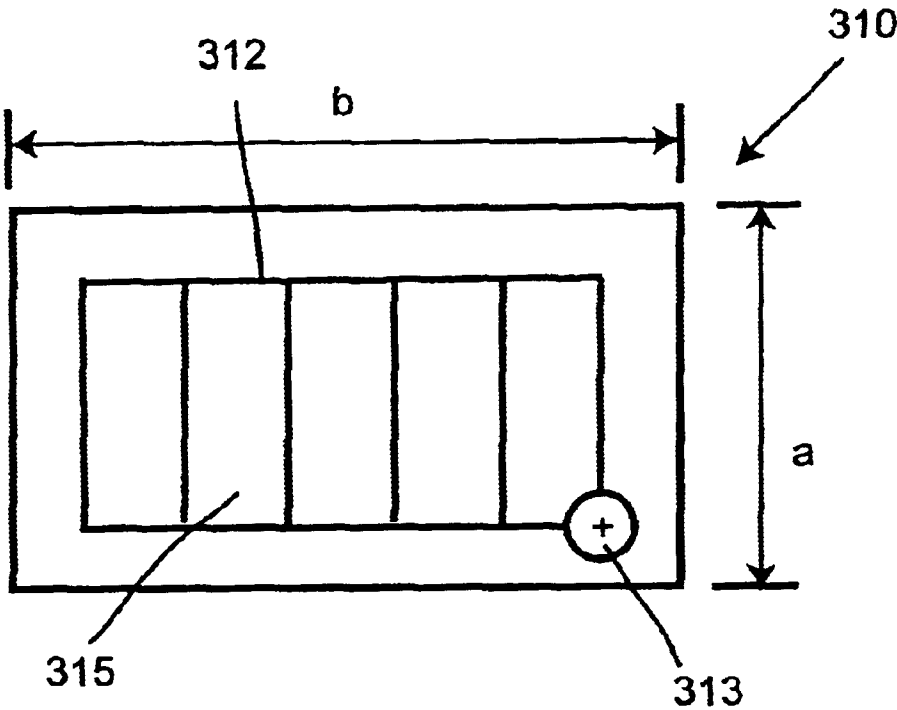


Fig. 4b

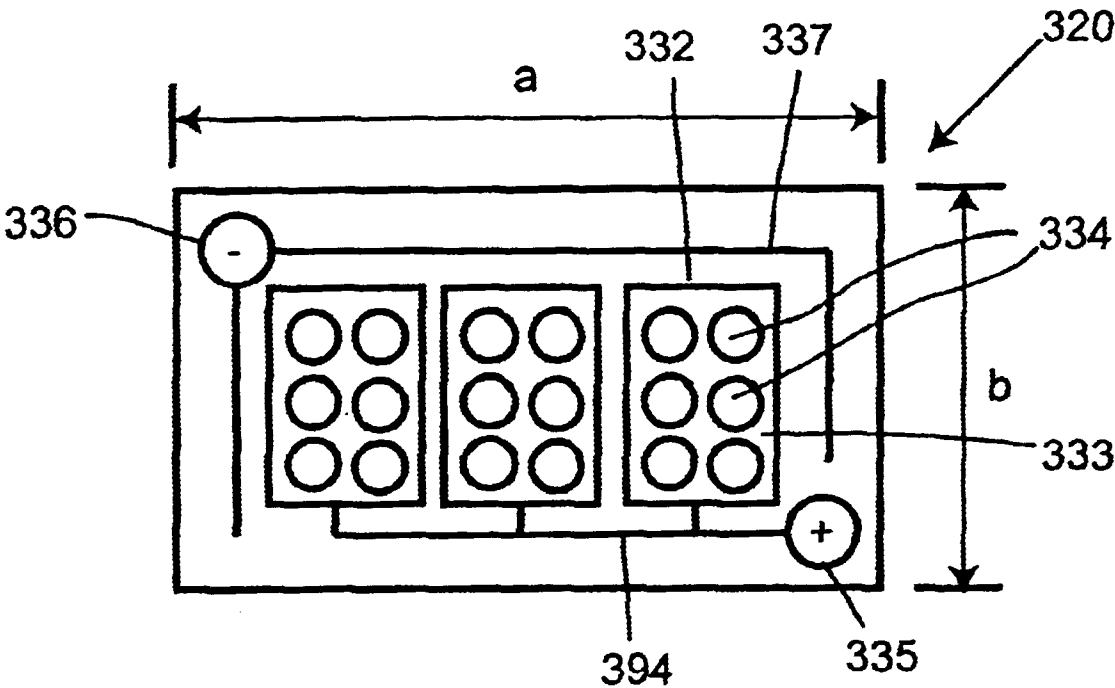


Fig. 4c

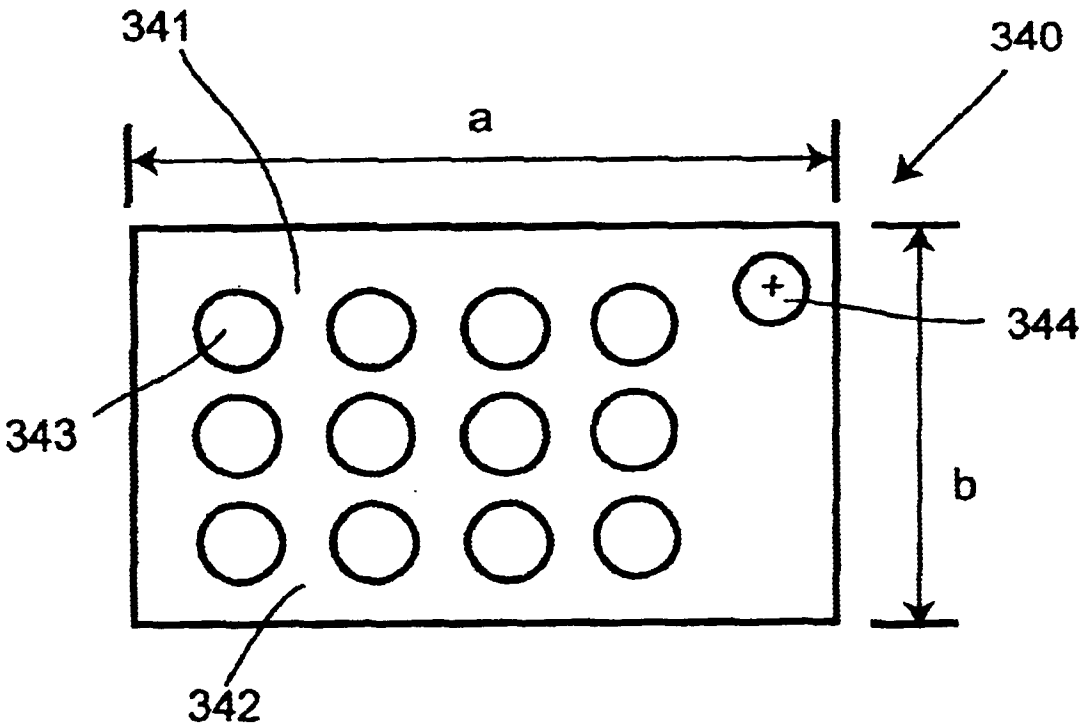


Fig. 4d

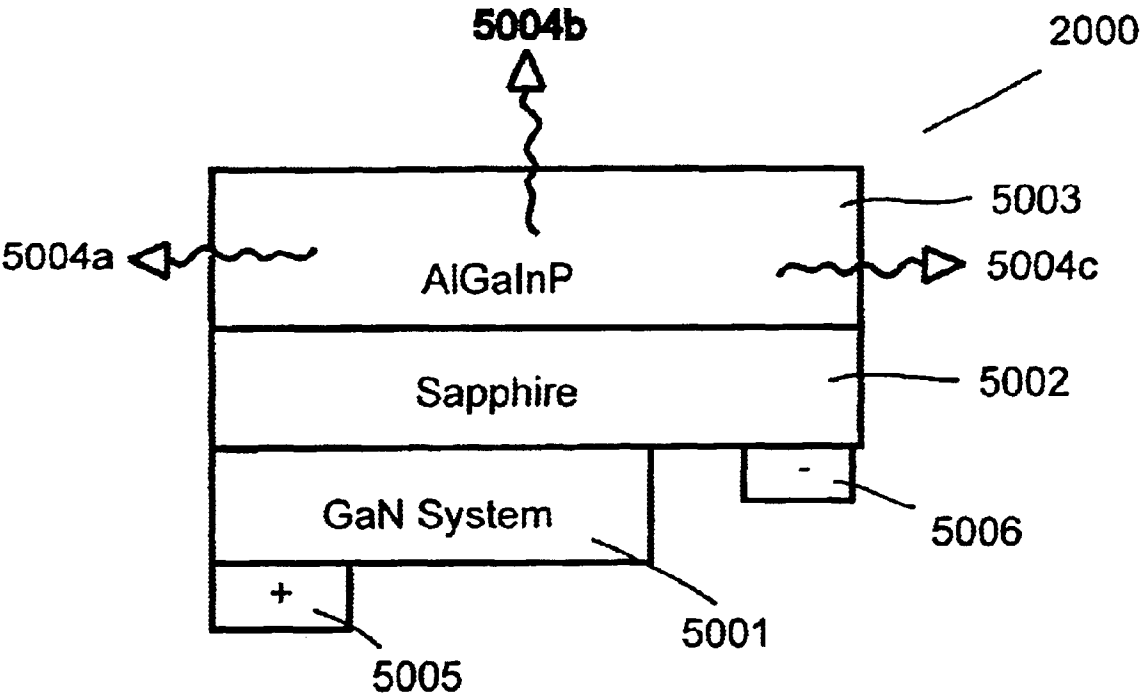


Fig. 5a

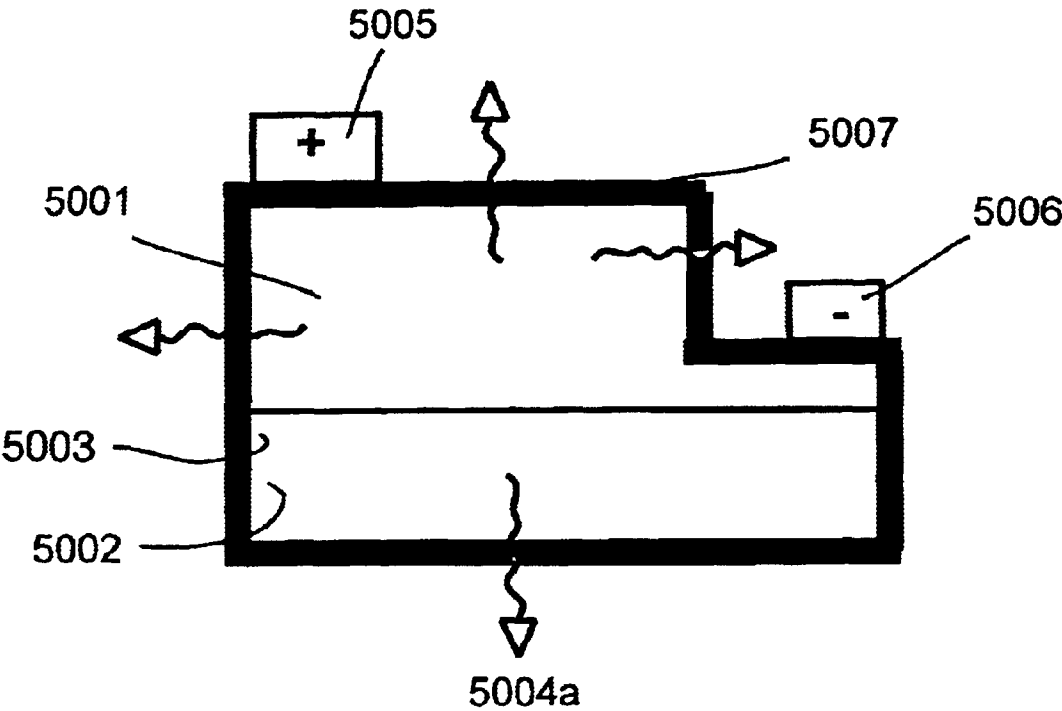


Fig. 5b

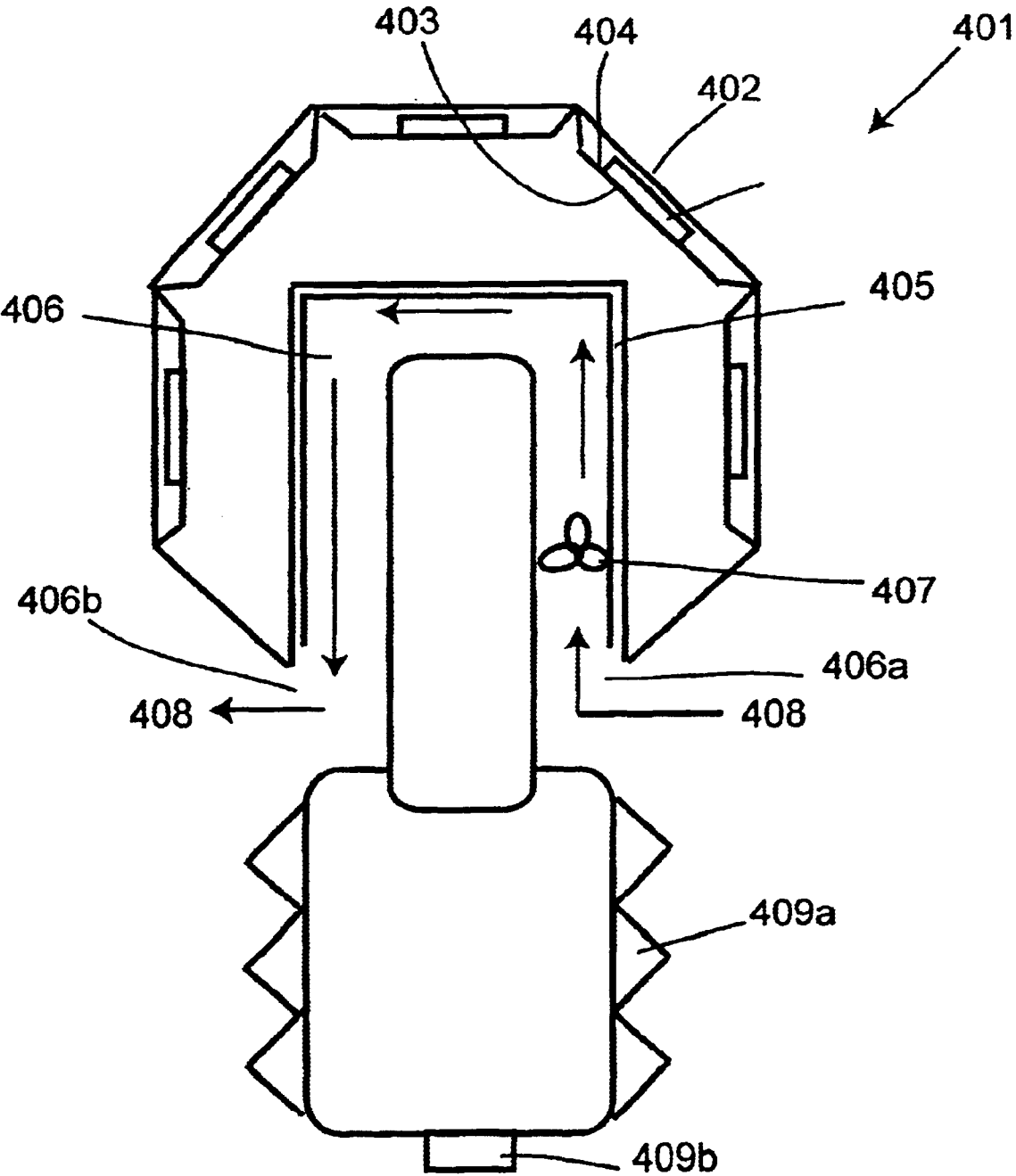


Fig. 6

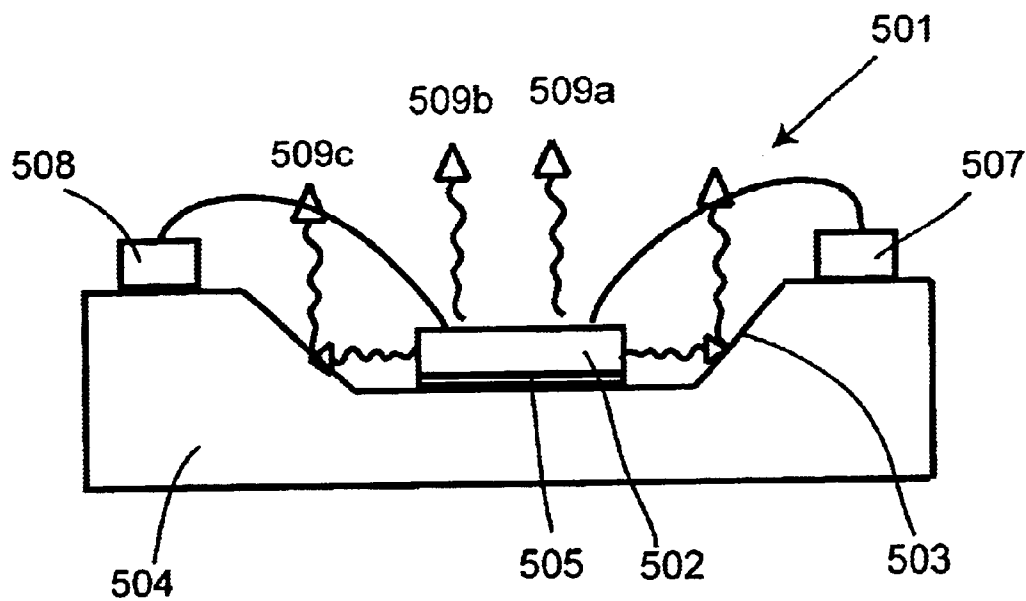


Fig. 7a

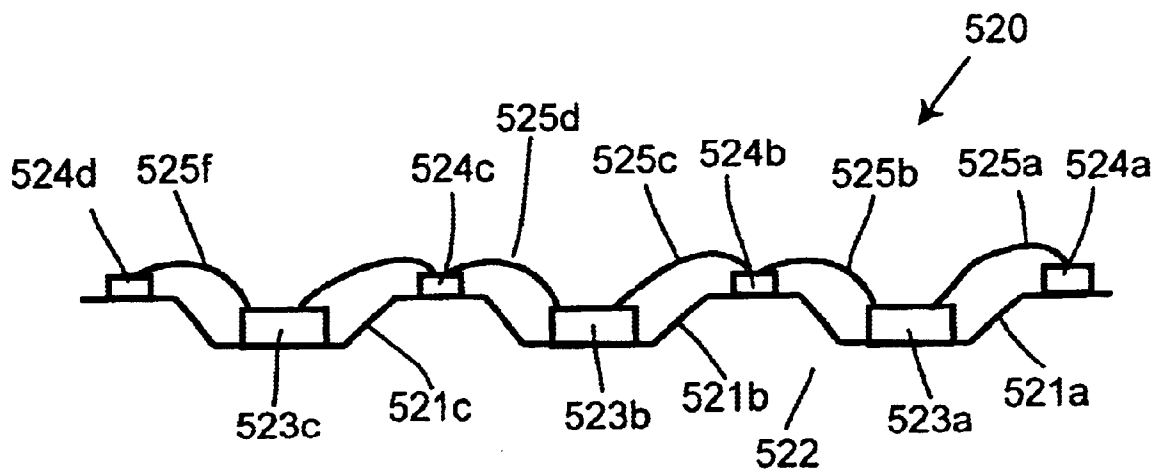


Fig. 7b

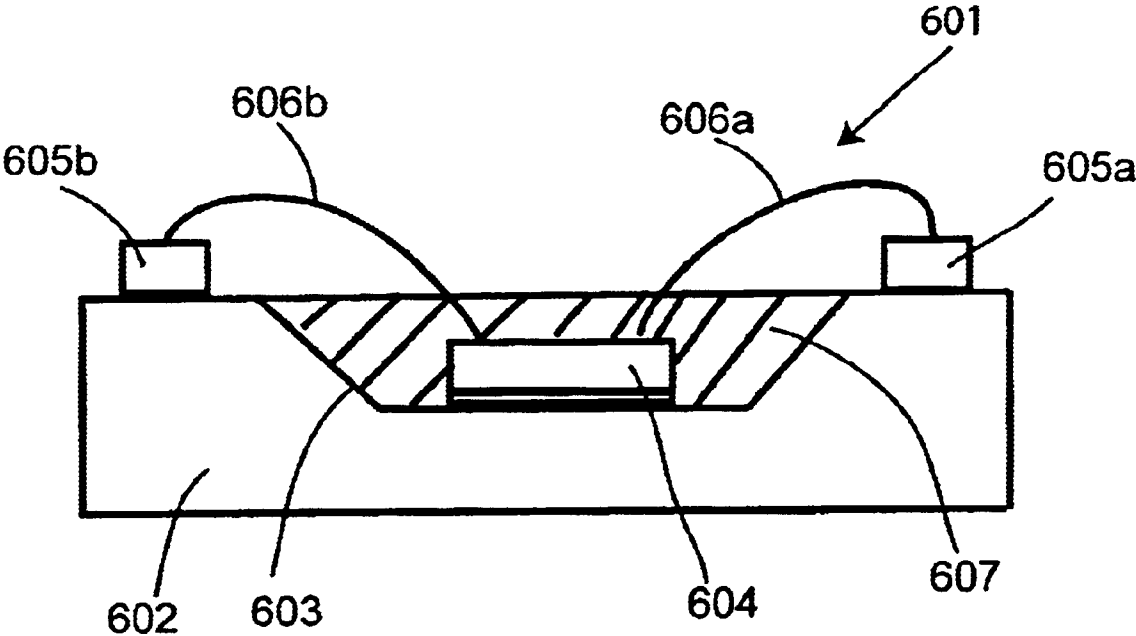


Fig. 8a

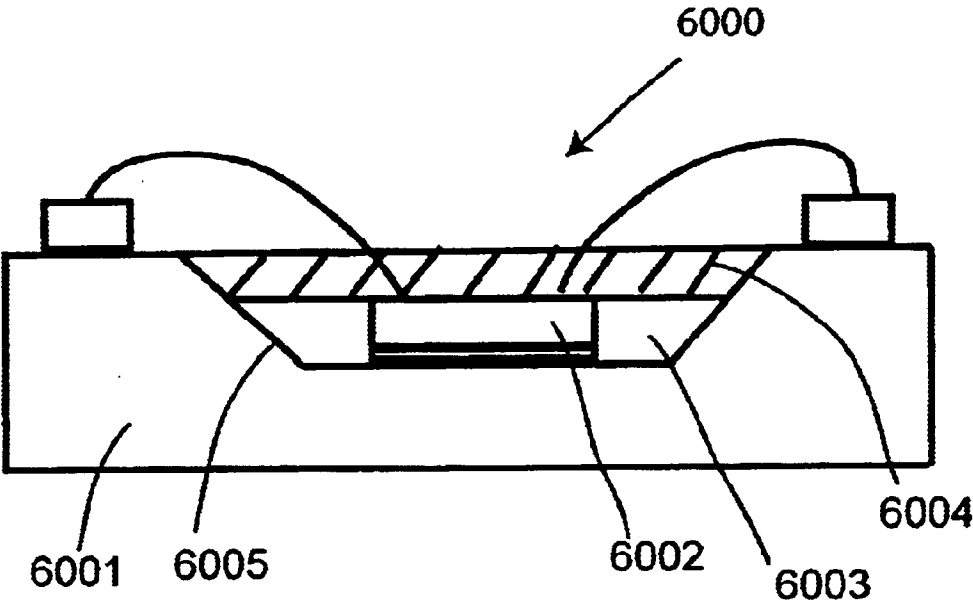


Fig. 8b

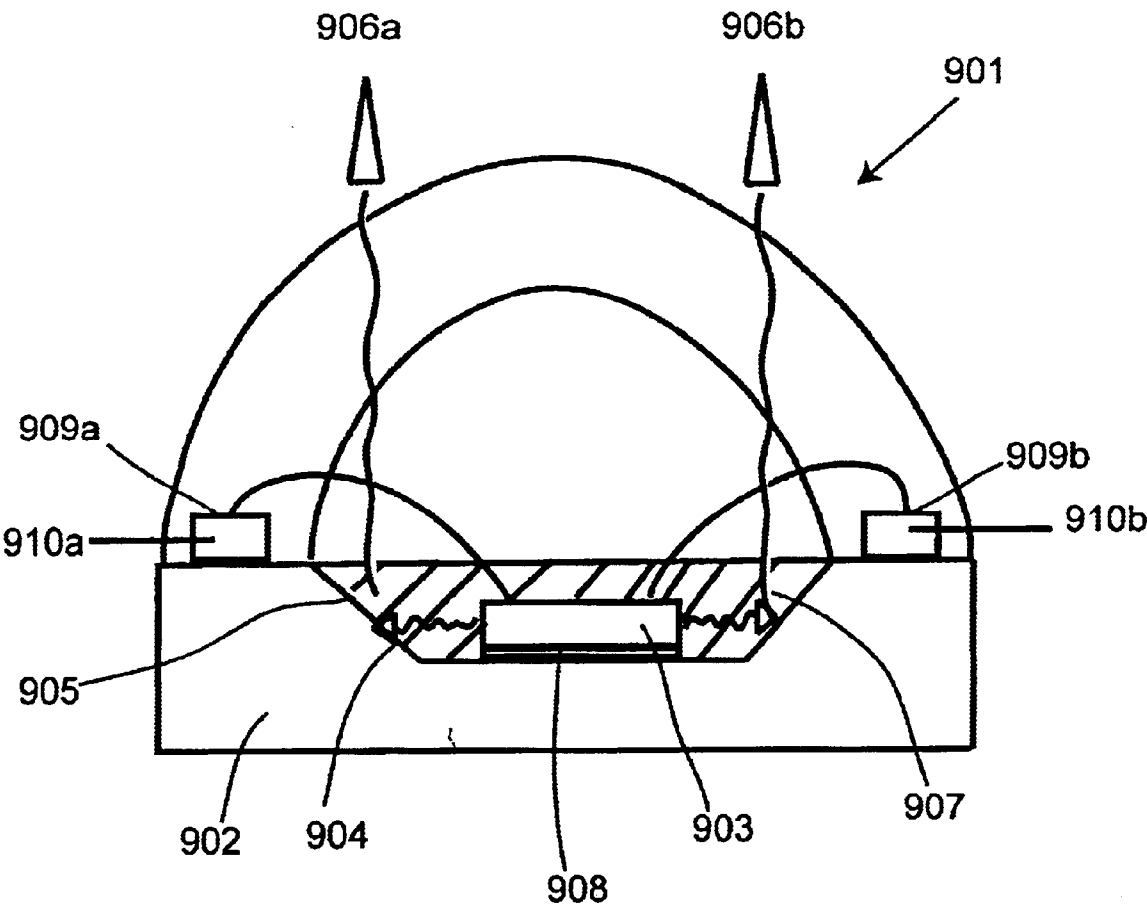


Fig. 9



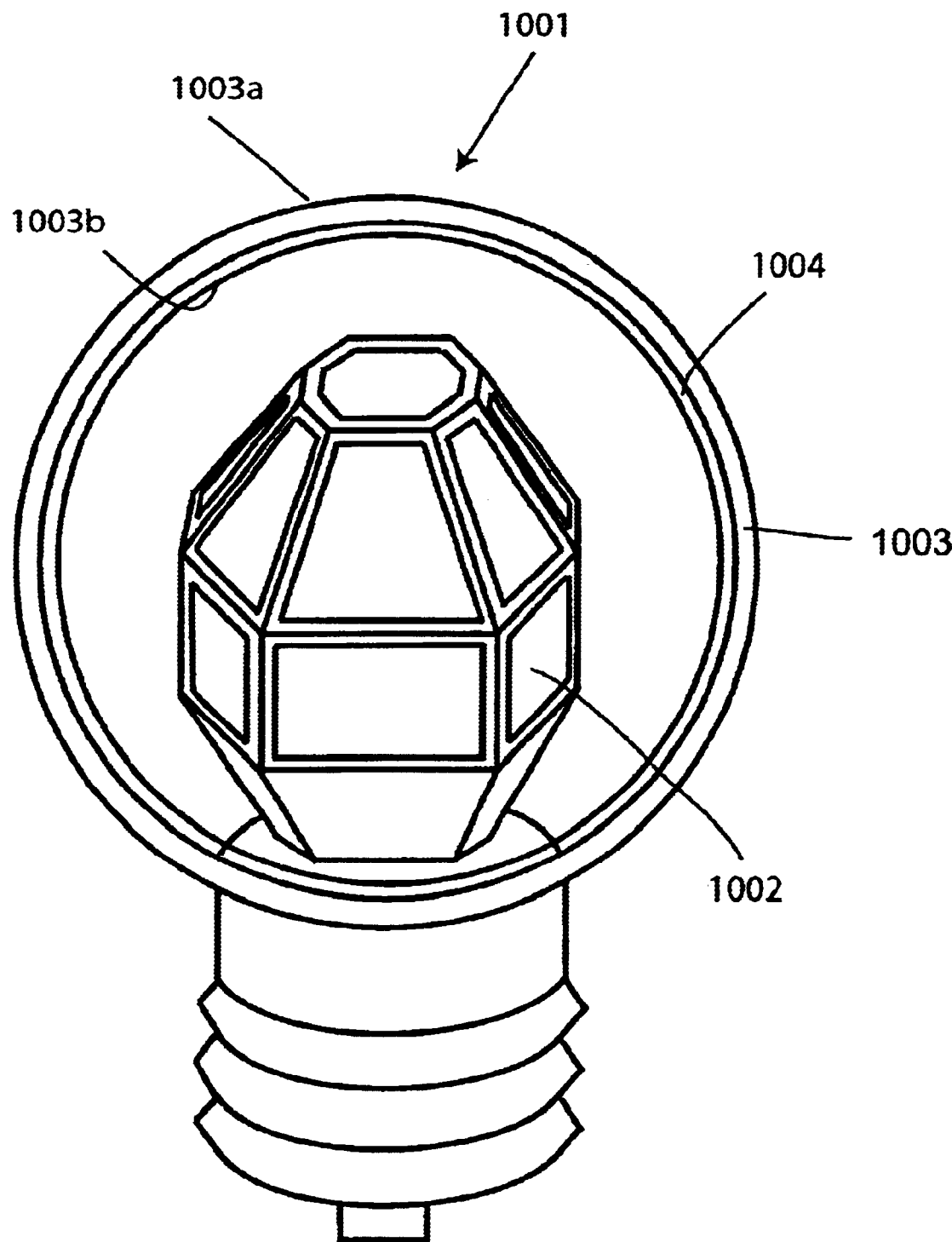


Fig. 10

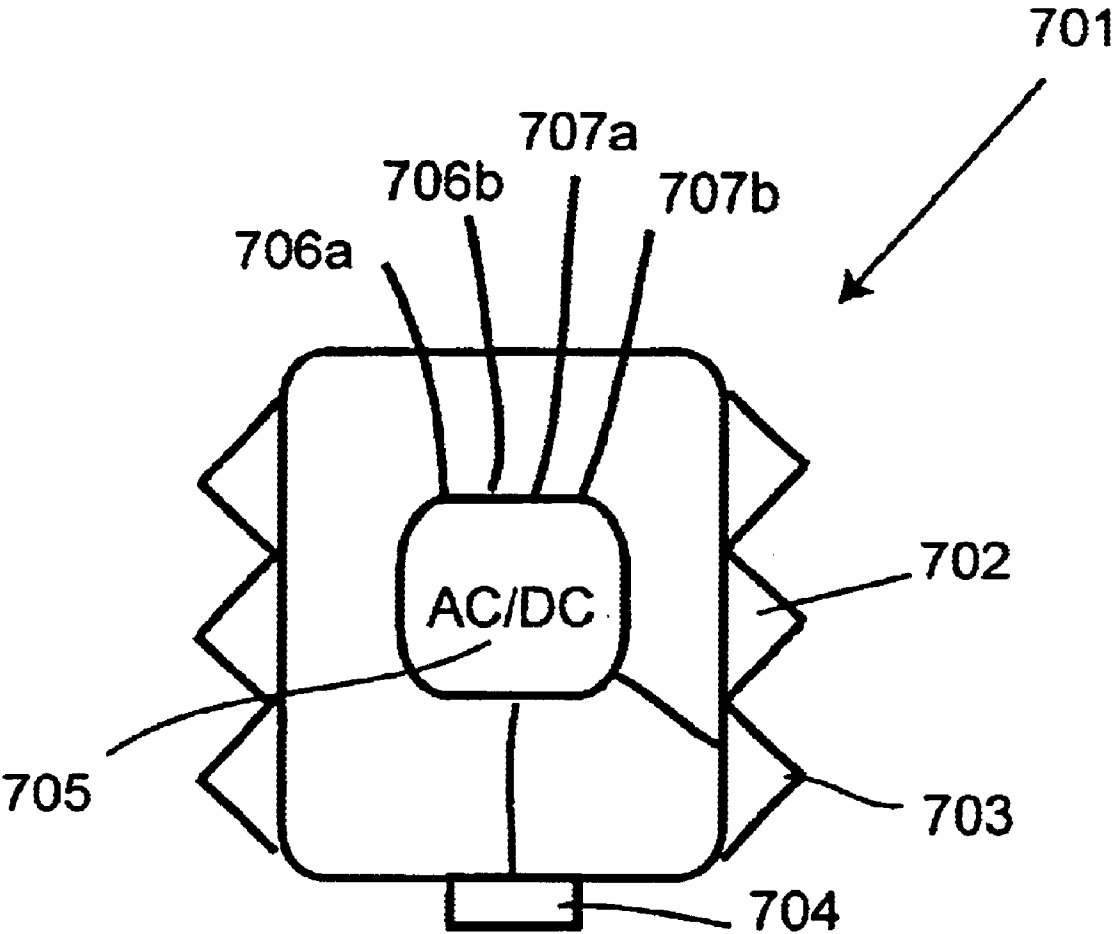


Fig. 11

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**LIGHT SOURCE USING SEMICONDUCTOR  
DEVICES MOUNTED ON A HEAT SINK**

**BACKGROUND OF INVENTION**

The invention relates to the field of light sources and illumination devices. More particularly, the invention relates to semiconductor light sources and illumination devices useful for providing visible light in order to partially or fully illuminate a space occupied by or viewed by humans, such as residential space, commercial space, outdoor space, the interior or exterior of a vehicle, etc.

In the prior art, light emitting diodes ("LED's") and other semiconductor light sources were traditionally used for panel displays (such as laptop computer screens), signal lighting, and other instrumentation purposes. LED's are desirable because they are a high efficiency light source that uses substantially less energy and creates less heat than typical prior art light sources such as incandescent and halogen lights. Prior art semiconductor light sources have not been successfully and economically used to illuminate physical spaces. Additionally, in the prior art, LED's were typically individually packaged in a module, either with or without a focus dome on the module. Typical prior art LED modules lack high light intensity due to the size of the LED chips used. Further, arranging a sufficient number of prior art LED modules to generate high light intensity, such as use of a stack, lamp or array, took an excessive amount of physical space and created unmanageable amounts of heat. Consequently, in the prior art, LED's and other semiconductor light sources were not suitable for replacing the traditional tungsten light bulbs.

U.S. Pat. No. 5,941,626 discloses a long light emitting apparatus that uses a plurality of LED lamps (modules) connected in series. The LED modules are spaced apart and appear to be intended for decorative use, such as on street lamp poles and on Christmas trees.

U.S. Pat. No. 5,160,200 discloses a wedge-base LED bulb housing. The patent depicts a plurality of separate LED modules electrically connected to a wedge base.

U.S. Pat. No. 4,675,575 discloses light-emitting diode assemblies such as a mono-color or bi-color light string system. Each LED is in an envelope with light conducting optical spheres for light transmission and dispersion. The LED string system appears adapted for decorative use, such as for lighting Christmas trees.

A distinct need is felt in the prior art for a semiconductor light source for use in illuminating a space with single color light in the visible range and which can efficiently dissipate the heat that they produce. Presently, that application is served by incandescent and fluorescent lights which have high energy consumption, high heat generation, and short useful life compared to the invented semiconductor light sources.

**SUMMARY OF INVENTION**

It is an object of some embodiments of the invention to provide a semiconductor light source capable of illuminating a space with visible light. These and other objects of various embodiments of the invention will become apparent to persons of ordinary skill in the art upon reading the specification, viewing the appended drawings, and reading the claims.

**BRIEF DESCRIPTION OF DRAWINGS**

FIG. 1 depicts a semiconductor light source of one embodiment of the invention using a high power chip or array arrangement.

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FIG. 2 depicts a semiconductor light source of one embodiment of the invention using high power surface mount LED chip modules or lamps.

FIG. 3a depicts an LED with an insulating substrate.

FIG. 3b depicts a detailed view of an LED structure on a sapphire substrate.

FIG. 3c depicts an LED with a conducting substrate.

FIG. 3d depicts a detailed view of an LED structure on a sapphire substrate.

FIG. 3e depicts a VCSEL chip on an insulating substrate.

FIG. 3f depicts a detailed view of a VCSEL chip on an insulative substrate.

FIG. 3g depicts a VCSEL chip on a conductive substrate.

FIG. 3h depicts a detailed view of a VCSEL chip in a conductive substrate.

FIG. 4a depicts a top view of an LED array on a single chip with an insulating substrate.

FIG. 4b depicts a top view of an LED array on a single chip with a conductive substrate.

FIG. 4c depicts a top view of a VCSEL array on a single chip with an insulating substrate.

FIG. 4d depicts a top view of a VCSEL array on a single chip with a conductive substrate.

FIG. 5a depicts a semiconductor chip of the invention that emits single color light using a conversion layer.

FIG. 5b depicts a semiconductor chip of the invention that emits single color light using a phosphor coating.

FIG. 6 depicts a cross sectional view of a heat sink of the invention using a fan and TE cooler to circulate air and remove heat.

FIG. 7a depicts a single chip or single array chip package.

FIG. 7b depicts a multiple chip package.

FIG. 8a depicts a chip package with phosphor covering on the semiconductor.

FIG. 8b depicts a chip package with a uniform phosphor coating.

FIG. 9 depicts a high power LED package.

FIG. 10 depicts an LED or laser light source located in a light enclosure having a phosphor coating.

FIG. 11 depicts a power supply module with fitting for a light source of the invention.

**DETAILED DESCRIPTION**

Referring to FIG. 1, one embodiment of the invention is depicted. In this embodiment of the invention, a semiconductor light source 100 is depicted. The light source 100 includes a traditional bulb-shaped enclosure 101. The enclosure 101 may be of any desired shape, including spherical, cylindrical, elliptical, domed, square, n-sided where n is an integer, or otherwise. The enclosure may be made from any desired light transparent or translucent materials, including glass, plastic, polycarbonate, and other light transparent materials.

The enclosure 101 has an exterior surface 101a and an interior surface 101b. The exterior surface 101a may be smooth and glossy, matte, or another finish or texture. The exterior surface 101a may be coated or painted with desired materials. The interior surface 101b may optionally include an appropriate coating, such as a luminous powder coating. Examples of luminous powder coating that may be used in the invention include YAG:Ce or other phosphor powders or coatings. For example, if the light source uses blue LED's to

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generate light, but it is desired to illuminate a room with white light, the interior surface **101b** maybe covered with a phosphor coating to convert blue light into white light. Any wavelength-modifying coating such as phosphor or another coating may be used. In some preferred embodiments of the invention, it is intended to convert light emitted by a semiconductor chip in the wavelength range of about 200 to about 700 nm. to white light.

The enclosure **101** encloses an interior volume **102** which may be a vacuum, or may contain a gas such as ordinary air, an inert gas such as argon or nitrogen, or any other desired gas. In some embodiments of the invention, a gas will be included within the interior volume **102** for the purpose of avoiding oxidation of the heat sink and the semiconductor.

The enclosure **101** may be mounted to a support **105**. The support **105** may be a separate component or may be integral with the base **103**. The base **103** may be configured as a fitting or connector for use in a desired light socket, such as a traditional light socket. In such case, the base **103** would also include electrodes **103a** and **103b** for making electrical connection with a power source.

Located within the interior volume **102** is at least one heat sink **104**. The heat sink **104** may be of any desired shape, depending on the application. As depicted, the heat sink **104** has a generally flat or planar top **104a**, and a plurality of generally flat or planar panels or compartment **104b**, **104c**, **104d**, **104e**, **104f**, **104g**, **104h**, **104i**, etc. each of which may host a single or an array of semiconductor devices capable of producing light. The heat sink **104** may be shaped otherwise, with curved or rounded sides.

If the heat sink **104** may be mounted on a support **105**, the support **105** may be designed in order to place the heat sink in the most desirable position within the interior volume **102** so that semiconductors located on the heat sink may emit light that will be transmitted in a diffuse or focused pattern through the enclosure **101**.

Mounted on the heat sink **104** are at least one semiconductor device **106**. The semiconductor device(s) **106** may be arranged in this embodiment of the invention to transmit light in all directions except through the base **103**, or in a manner to direct light in a specific direction. The semiconductor devices may be any semiconductor devices capable of emitting light, such as LED's, LED arrays, VCSEL's, VCSEL arrays, photon recycling devices that cause a monochromatic chip to emit white light, and others.

The semiconductor devices **106** are electrically connected to each other via electrical connections **107**. Lead wires **108a** and **108b** are used to provide the semiconductor devices **106** with electrical power. As desired, the heat sink may serve as a positive or negative electrical connection for the semiconductor devices.

The heat sink **104** may be any material capable of conducting heat away from the semiconductor devices. Examples of suitable materials include copper, aluminum, silicon carbide, boron nitride and others known to have a high coefficient of thermal conductivity.

In order to provide suitable electrical power to the semiconductor devices, an AC/DC converter (not shown in this fixture) is utilized. This will permit the invented semiconductor light source to be powered by 110V. or 220V. AC power found in homes and businesses throughout the world. The AC/DC converter may be located in the base **103** or in another location.

In alternative embodiments of the invention, each semiconductor device may have its own individual heat sink, or two or more semiconductor devices may be located on the

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same heat sink. In some embodiments of the invention, the base may also serve as a heat sink, eliminating the need for a separate heat ink and thereby reducing cost.

Referring to FIG. 2, a semiconductor device **2220** in enclosure **2201** can be arranged to accommodate high power surface LED's. "High power" LED's means that the light output from each LED module is greater than 40 milliwatts. "Surface mount" LED's are LED's mounted directly on a heat sink, or other surface, in contrast with traditional LED lamps which have ordinary electrical leads for wiring and must be separately held in place. High power surface mount LED's are described in detail later in this document.

When high power LED's are used, all the components are the same as in FIG. 1 except that a high power LED **2206** is used. It can be seen that the LED's **2206** are electrically connected with electrical connectors **2207** and are located on a heat sink **2204**. The heat sink **2204** has a plurality of heat sink faces **2210**, **2211** and **2212** which are each generally planar and are arranged in angular orientation with each other in order to cause light from the LED's to be dispersed around a space to be illuminated. The heat sink faces can be oriented with respect to each other at any desired angle, but 45 degree angles are depicted in the figure so that face **2210** is perpendicular to face **2212**. A standard base **2203** is provided.

Any of the semiconductor light sources described below and others may be used in embodiments of the invention.

FIG. 3a depicts an LED chip with an insulating substrate **201**. The substrate **202** may be an appropriate material on which a semiconductor may be grown, such as sapphire, gallium arsenide, silicon carbide, gallium phosphorous, gallium nitride and others. The substrate **202** will also in this embodiment be electrically insulative. The semiconductor material **203** will emit light in all directions as indicated by arrows **204a**, **204b**, **204c** and **204d**. Positive **205a** and negative **205b** electrodes are provided for powering the chip.

FIG. 3b depicts an example of epitaxial layer configuration for the LED of FIG. 3a. A light emitting diode on an electrically insulative substrate **1200** is depicted. The LED includes an electrically insulative substrate such as sapphire **1201**. The substrate serves as a carrier, pad or platform on which to grow the chip's epitaxial layers. The first layer placed on the substrate **1201** is a buffer layer **1202**, in this case a GaN buffer layer. Use of a buffer layer reduces defects in the chip which would otherwise arise due to differences in material properties between the epitaxial layers and the substrate. Then a conductive layer **1203** is provided, such as n-GaN. This layer acts as a connector for a negative electrode. Then a cladding layer **1204**, such as n-AlGaIn, is provided. Cladding layers serve to confine the electrons as they jump from a conduction band to valance and give up energy that converts to light. An active layer **1205** p-InGaIn is then provided where electrons jump from a conduction band to valance and emit energy which converts to light. On the active layer **1205**, another cladding layer **1206**, such as p-AlGaIn is provided that also serves to confine electrons. A contact layer **1207** such as p+-GaIn is provided that is doped for Ohmic contact. The contact layer **1207** has a positive electrode **1208** mounted on it, in this case an electrode that has a mount side on the contact layer **1207** that is Ni and an electrode face that is Au. A similar negative electrode is provide on a shelf of the first cladding layer **1203**.

FIG. 3c depicts an LED with a conducting substrate **210**. The substrate **211** must be an electrically conductive material on which a semiconductor ship may be grown, such as gallium arsenide, silicon carbide, gallium phosphorous, gal-

lithium nitride and others. A portion of the substrate **212** will serve as an electrode for powering the chip, in this case a negative electrode. The semiconductor material **213** will emit light in all directions as indicated by arrows **214a**, **214b**, **214c** and **214d**. A positive electrode **215** is provided, and the base **240** of the substrate **211** acts as a negative electrode. The base **240** is made of any conductive metal such as Au, Au/Ce, An/Zn and others.

FIG. **3d** depicts epitaxial layer configuration for the LED of FIG. **3c**. A light emitting diode grown on an electrically conductive substrate **1210** is depicted. The LED includes an electrically conductive substrate such as SiC **1212**. The substrate serves as a carrier, pad or platform on which to grow the chip's epitaxial layers, and as a negative electrode in the chip. The first layer placed on the substrate **1212** is a buffer layer **1213**, in this case a GaN buffer layer. Next, a cladding layer **1214** is provided, such as n-GaN. An active layer **1215** p-InGaIn is provided where energy is converted to light. On the active layer **1215**, another cladding layer **1216**, such as p-AlGaIn is provided. A contact layer **1217** such as p+-GaIn that has a positive electrode **1218** mounted on it. A negative electrode **1211** is provided at the base of the chip.

FIG. **3e** depicts a VCSEL chip on an insulating substrate **220**. The substrate **221** has a volume of semiconductor material **222** on it. Positive electrodes **223a** and **223b** and negative electrodes **224** are provided for powering the chip, and light is emitted from the chip in directions generally indicated by arrows **225a** and **225b**.

FIG. **3f** depicts epitaxial layer configuration of the VCSEL chip of FIG. **3e** with an electrically insulative substrate **1220**. The chip **1220** includes a substrate **1221** that has electrically insulative properties such as sapphire. On top of the substrate **1221** there is a buffer layer **1222** such as GaN followed by a cladding layer and contact layer **1223** such as n-GaN. The cladding layer **1223** includes a negative electrode **1232c**. Next, there is another cladding layer nGaInN **1224**. A reflective layer AlN/AlGaIn MQW (multiple quantum wells) **1225** is provided. A cladding layer **1226** n-AlGaIn is interposed between the reflective layer **1225** and the active layer **1227** GaInN MQW. The active layer **1227** is followed by another cladding layer p-AlGaIn **1228** which is followed by a second reflective layer **1229** AlN/AlGaIn MQW. Light emitted from the active layer reflects between the two reflective layers until it reaches an appropriate energy level and then lases, emitting a laser beam of light. The second reflective layer **1229** is followed by a cladding layer p AlGaIn **1230** and a contact layer p+-GaIn **1231**. The contact layer may be ring-shaped with a window opening **1233** and has one or more positive electrodes **1232a** and **1232b** which are contact areas. The negative electrode is created on the n-GaN layer.

FIG. **3g** depicts a VCSEL chip on a conductive substrate **230**. The substrate **231** has a volume of semiconductor material **232** on it. Positive electrodes **233a** and **233b** are provided for powering the chip, and light is emitted from the chip in directions generally indicated by arrows **235a** and **235b**. The base **236** of the substrate **231** serves as a negative electrode.

FIG. **3h** depicts epitaxial layer configuration of a VCSEL chip with an electrically conductive substrate **1239** such as that of FIG. **3g**. The chip **1239** includes a substrate **1241** that has electrically conductive properties such as SiC. The underside of the substrate **1241** has an electrode **1240**. On top of the substrate **1241** there is a buffer layer **1242** such as GaN followed by a cladding layer **1243** such as n-GaN.

Next, there is another cladding layer NGaInN **1244**. A reflective layer using AlN/AlGaIn MQW (multiple quantum wells) **1245** is then provided. A cladding layer **1246** n-AlGaIn is interposed between the first reflective layer **1245** and the active layer **1247** GaInN MQW. The active layer **1247** is followed by another cladding layer p-AlGaIn **1248** which is followed by a second reflective layer **1249** AlN/AlGaIn MQW. The second reflective layer **1249** is followed by a cladding layer p AlGaIn **1250** and a contact layer p+-GaIn **1251**. The contact layer may have one or more positive electrodes **1252a** and **1252b** mounted on it.

FIG. **4a** depicts a top view of an LED array on a single chip with a size axb on an insulating substrate **301**. Each of sizes a and b is greater than 300 micro meters. Semiconductor materials **302** are located on an electrically insulative substrate (not shown). Positive **303** and negative **304** pads are provided, each in electrical connection with its respective metal strip **305** and **306** arranged in a row and column formation (8 columns shown) to create the array and power the chip. This enables the LED to emit high power light from a single chip.

FIG. **4b** depicts a top view of an LED array on a single chip with a size axb on a conductive substrate **310**. Each of sizes a and b is greater than 300 micro meters. Semiconductor materials **312** are located on an electrically conductive substrate (not shown). Positive pad **313** is provided in electrical connection with a metal strip **315** arranged in an array formation to power the chip. The substrate **310** serves as the negative electrode in the embodiment depicted.

FIG. **4c** depicts a top view of a VCSEL array on a single chip with a size axb on an insulating substrate **320**. Each of sizes a and b is greater than 300 micro meters. The chip **320** includes an electrically insulative substrate (not shown) on which a semiconductor material **332** is located covered by a panel **333**. The panel **333** may be an appropriate conductive material such as Au/Ce, Au/Zn and others. The panel **333** has a plurality of windows **334** in it to permit light produced by the semiconductor material **332** to be emitted for use. The panel **333** is electrically connected to conductive metal strip **340** and to an electrode pad **335**. A negative electrode pad **336** is also provided in electrical conduction with a metal strip **337** to power the chip.

FIG. **4d** depicts a top view of a VCSEL array on a single chip with a dimension axb on a conductive substrate **340**. Each of sizes a and b is greater than 300 micro meters. It includes a conductive substrate (not shown) on which a semiconductor material **341** is located. A conductive panel **342** overlays the semiconductor material **341**. A plurality of windows **343** are provided in the panel **342** to allow light produced by the chip to escape for us. A positive electrode pad **344** is provided which in conjunction with the electrically conductive substrate serving as a negative electrode power the chip. A negative electrode is provided on the bottom of the chip **340**.

FIGS. **5a** and **5b** depict a semiconductor chip system that emits white light. In FIG. **5a**, there is a GaN based semiconductor chip **2000** depicted. It includes a GaN system **5001** built on an insulative sapphire substrate **5002** capable of emitting blue light, the general structure of which is known in the prior art. A light conversion layer **5003** such as AlGaInP (aluminum gallium indium phosphate) adjacent the sapphire layer **5002** opposite the GaN system **5001**. Light emitted from the GaN system will travel through the sapphire layer **5002**, through the AlGaInP **5003** to exit the chip system. Some of the blue light will be absorbed by the AlGaInP to emit yellow light, and some of the blue light will



be transmitted through the AlGaInP. The combination of blue and yellow light emitted by the chip according to arrows **5004a**, **5004b** and **5004c** will appear as white light to human eyes. Electrodes **5005** and **5006** are provided for electrical connection. Referring to FIG. **5b**, the chip **2000** is depicted following application of an exterior light conversion coating or layer **5007** such as phosphor. Light which exits through the phosphor such as **5004a** will be converted in wavelength to white, making a useful light for illuminating physical spaces. A coating or layer to convert monochromatic light to white light may include phosphor powder, YAG/Ce and others. Such a coating or layer may be applied by the methods of brush coating, flow coating and evaporative coating.

FIG. **6** depicts a cross sectional view of a heat sink of the invention **401**. As depicted in this embodiment, a plurality of semiconductor chips or high power LED's **402** capable of emitting light are mounted in a well of the heat sink material **403** (surface mounting). The mounting of the chips or high power LED's may be achieved by use of a heat-conductive adhesive **404**, or by brazing or mechanical fixation. The heat sink material **403** is of sufficient thickness to conduct heat away from the chips **402** and keep the chips cool. Located within the heat sink **403**, a layer or lining of thermal electric material **405** may be installed. Thermal electric ("TE") material experiences a reduction in temperature when voltage is applied to it. By applying a voltage to the TE material **405**, its temperature can be lowered and heat can be drawn from the heat sink material **403** that in turn is drawing heat away from the chips **402**. The TE material may line an air chamber **406**. The air chamber is open at its entrance **406a** and at its exit **406b**. A fan **407** may be placed in or near the air chamber **406** in order to cause air **408** to travel in the entrance **406a**, through the air chamber **406** past the TE material **405** and out of the exit **406b**, carrying heat with it. Such a system will increase efficiency of heat dissipation from the chips **402**. At the bottom of the heat sink, a fitting or connector may be provided that is threaded **409a** and has an electrode **409b** for installation into a traditional light socket.

FIG. **7a** depicts a single chip or single array chip surface mount package **501**. It includes a semiconductor chip or array **502** capable of emitting light mounted in a well **503** of a heat sink **504**. The well **503** is provided with reflective sides to that light emitted from the sides of the chip or array **502** is reflected out of the well in order to provide useful illumination and to minimize heat buildup. The chip or array **502** may be mounted in the well **503** by use of a heat conductive adhesive **505** or by brazing or mechanical fixation. The heat conductive adhesive may also be used as a reflector to reflect light from the substrate in the direction of arrows **509a** and **509b**. Connection blocks **507** and **508** may be mounted on the heat sink **504** in order to facilitate electrical connection of the chip **502**. Light exits the chip as indicated by arrows **509a**, **509b** and **509c**.

FIG. **7b** depicts a multiple chip package **520**. It includes multiple wells **521a**, **521b** and **521c** on a heat sink **522** in which multiple chips or arrays **523a**, **523b** and **523c** are located. Connection blocks **524a**, **524b**, **524c** and **524d** are provided with lead wires **525a**, **525b**, **525c**, **525d** and **525f** in order to electrically power the chips or arrays.

FIG. **8a** depicts a chip package with phosphor covering **601**. The package includes a heat sink **602** in which a well is located **603** for receiving a chip or array **604**. Connection blocks **605a** and **605b** and lead wires **606a** and **606b** may be used to electrically power the chip or array **604**. A thickness of phosphor **607** may be placed over the chip or array **604**

in order to convert single wavelength light emitted from the chip or array into multiple wavelength white light useful for illumination of spaces used by humans. FIG. **8b** depicts another phosphor coated chip package **6000**. It includes a heat sink **6001** on which a light emitting chip **6002** is mounted in a receptacle **6005** on the heat sink. The chip **6002** does not fill the entirety of the receptacle **6005** so a transparent filler **6003** of a material transparent to the wavelength of light emitted by the chip **6002** is provided. Some transparent materials which may be used include epoxy, plastic and others. On the face of the chip **6002** opposite the heat sink **6001** a wavelength conversion coating or layer **6004** is provided to convert the light emitted by the chip to white light. A phosphor coating is preferred.

FIG. **9** depicts a high power surface mount LED package **901** useful in the invention. The LED package **901** includes a heat sink **902** formed from a material which can dissipate heat. A well **904** is formed in the heat sink in order to accept an LED, laser diode or semiconductor chip array **903** therein. The well **904** has walls **905** for reflecting light **906a** and **906b** emitted by the chip(s) **903**. An optional phosphor coating **907** is provided over the chip(s) to convert light emitted by the chip(s) to white light. The chip(s) **903** are secured to the heat sink **903** by use of adhesive **908**. The adhesive **908** may be heat conductive to aid in transmission of heat from the chips to the heat sink, and it may have light reflective properties to aid in reflection of light from the chips in the direction of arrows **906a** and **906b** in a usable direction. Reflection of light by the well and the adhesive provides more efficient light output than would otherwise be achieved. Connection blocks **909a** and **909b** are provided for forming electrical connection with diodes **910a** and **910b**. A focus dome, lens, or cover **910** is provided that is transparent to the light being emitted. The focus dome may have the characteristic of serving to focus light being emitted from the chips in order to create a substantially coherent beam of usable light.

FIG. **10** depicts a light source of the invention **1001** having an LED or laser light source **1002** located in an enclosure **1003**. The enclosure may be any appropriate shape. The depicted shape is that of a bulb, but flat, arcuate, rounded or other shapes may be used depending on the application. The enclosure **1003** may be glass, plastic, polycarbonate or any other material that is substantially transparent to the light to be emitted. The enclosure **1003** has an exterior surface **1003a** and an interior surface **1003b**. The enclosure serves as a protector of the light source **1002** and it may be designed to diffuse light. The interior surface **1003b** of the enclosure may have a coating or layer **1004** which serves to alter properties of the light emitted from the light source **1002**. For example, if light from the light source **1002** is single wavelength, then the light-altering coating **1004** may be phosphorous which will turn the monochromatic light into white light. Other coatings may be used as desired to alter the light in other ways.

FIG. **11** depicts a power supply module **701** for a light source of the invention. The power supply module **701** includes a fitting or connector **702** with electrodes **703** and **704** for receiving AC electrical input from a traditional light bulb socket. An AC/DC converter **705** is provided to convert AC power from standard building wiring into DC power usable by the semiconductor chips of the invention. Electrical lead wires **706a** and **706b** are provided for electrical connection to the chips to power the light source, and electrical lead wires **707a** and **707b** are provided to provide power for the cooling fan TE cooler. The coating may be applied on the interior or exterior of the enclosure, or both.

Examples of some heat sink materials which may be used in the invention include copper, aluminum, silicon carbide, boron nitride natural diamond, monocrystalline diamond, polycrystalline diamond, polycrystalline diamond compacts, diamond deposited through chemical vapor deposition and diamond deposited through physical vapor deposition. Any materials with adequate heat conductance can be used.

Examples of heat conductive adhesives which may be used are silver based epoxy, other epoxies, and other adhesives with a heat conductive quality. In order to perform a heat conductive function, it is important that the adhesive possess the following characteristics: (i) strong bonding between the materials being bonded, (ii) adequate heat conductance, (iii) electrically insulative or electrically conductive as desired, and (iv) light reflective as desired. Examples of light reflective adhesives which may be used include silver and aluminum based epoxy.

Examples of substrates on which the semiconductors used in the invention may be grown include Si, GaAs, GaN, InP, sapphire, SiC, GaSb, InAs and others. These may be used for both electrically insulative and electrically conductive substrates.

Materials which may be used as a thermoelectric cooler in the invention include known semiconductor junction devices.

It will be preferred that the semiconductor light source of the invention will emit light in the wavelength range of 200 to 700 nm in order to be useful for illumination of a physical space used by humans.

Heat sinks used in this invention can be of a variety of shapes and dimensions, such as those depicted in the drawings or any others which are useful for the structure of the particular light source being constructed.

Any of the foregoing, including combinations thereof, and other semiconductors, materials and components may be used in the invented light sources.

While the present invention has been described and illustrated in conjunction with a number of specific embodiments, those skilled in the art will appreciate that variations and modifications may be made without departing from the principles of the invention as herein illustrated, as described and claimed. The present invention may be embodied in other specific forms without departing from its spirit or essential characteristics. The described embodiments are considered in all respects to be illustrative and not restrictive. The scope of the invention is, therefore, indicated by the appended claims, rather than by the foregoing description. All changes which come within the meaning and range of equivalence of the claims are to be embraced within their scope.

What is claimed is:

1. A semiconductor light source for emitting light to illuminate a space used by humans, the semiconductor light source comprising:

- an enclosure, said enclosure being fabricated from a material substantially transparent to white light,
- a base to which said enclosure is mounted,
- an interior volume within said enclosure,
- a secondary heat sink located in said interior volume, said secondary heat sink being capable of drawing heat from one or more semiconductor devices,
- a plurality of primary heat sinks mounted on said secondary heat sink, each of said primary heat sinks being smaller than said secondary heat sink,
- a semiconductor chip capable of emitting light mounted on one of said primary heat sinks, said semiconductor

chip being capable of emitting monochromatic light, said semiconductor chip being selected from the group consisting of light emitting diodes, light emitting diode arrays, laser chips, and VCSEL chips,

said chip including a substrate on which epitaxial layers are grown,

a buffer layer located on said substrate, said buffer layer serving to mitigate differences in material properties between said substrate and other epitaxial layers,

a first cladding layer serving to confine electron movement within the chip, said first cladding layer being adjacent said buffer layer,

an active layer, said active layer emitting light when electrons jump to a valance state,

a second cladding layer, said second cladding layer positioned so that said active layer lies between cladding layers, and

a contact layer on which an electron may be mounted for powering said chip, and

a coating for converting monochromatic light emitted by said chip to white light.

2. A device as recited in claim 1 further comprising a power module for powering the light source, said power module including a fitting for installation in a traditional light bulb socket and an AC/DC converter for converting AC power from traditional building wiring to DC power usable by a semiconductor devices.

3. A device as recited in claim 1 wherein at least one of said heat sink includes a material selected from the group consisting of include copper, aluminum, silicon carbide, boron nitride natural diamond, monocrystalline diamond, polycrystalline diamond, polycrystalline diamond compacts, diamond deposited through chemical vapor deposition and diamond deposited through physical vapor deposition.

4. A device as recited in claim 1 further comprising a quantity of heat conductive adhesive located between said chip and said primary heat sink and serving to conduct heat from said chip to said primary heat sink.

5. A device as recited in claim 1 further comprising a quantity of light reflective adhesive located between said chip and said primary heat sink.

6. A device as recited in claim 1 further comprising a first and a second reflective layers, each of said first and second reflective layers being located on opposite sides of said active layer, said reflective layers serving to reflect light emitted by said active layer.

7. A device as recited in claim 6 wherein said reflective layers include multiple quantum wells.

8. A device as recited in claim 1 wherein said substrate is selected from the group consisting of Si, GaAs, GaN, InP, sapphire, SiC, GaSb, InAs.

9. A device as recited in claim 1 wherein said substrate is electrically conductive.

10. A device as recited in claim 1 wherein said substrate is electrically insulative.

11. A device as recited in claim 1 wherein at least one of said epitaxial layers includes a material selected from the group consisting of GaN, AlGaIn, AlN, AlGaIn, GaInN, and GamiN.

12. A device as recited in claim 1 wherein said coating for converting monochromatic light is a phosphor coating located on said chip.

13. A semiconductor light source for creating white light to illuminate a space used by humans, the semiconductor light source comprising:

- an enclosure, said enclosure being fabricated from a material substantially transparent to white light,

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an interior volume within said enclosure,  
a heat sink located in said interior volume, said heat sink  
being capable of drawing heat from one or more  
semiconductors devices,  
a plurality of semiconductor devices located in said interior volume,  
said semiconductor devices being capable of emitting  
light,  
at least one of said semiconductor devices including  
a substrate on which epitaxial layers are grown,  
a buffer layer located on said substrate, said buffer layer  
serving to mitigate differences in material properties  
between said substrate and other epitaxial layers,  
a first cladding layer serving to confine electron move-  
ment within the chip, said first cladding layer being  
adjacent said buffer layer,  
an active layer, said active layer emitting light when  
electrons jump to a valance state,  
a second cladding layer, said second cladding layer  
positioned so that said active layer lies between  
cladding layers, and

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a contact layer on which an electron may be mounted  
for powering said chip.  
14. A device as recited in claim 13 further comprising a  
coating for converting monochromatic light emitted by at  
least one of said semiconductor devices to white light.  
15. A device as recited in claim 13 further comprising a  
first and a second reflective layers, each of said first and  
second reflective layers being located on opposite sides of  
said active layer, said reflective layers serving to reflect light  
emitted by said active layer.  
16. A device as recited in claim 15 wherein said reflective  
layers include multiple quantum wells.  
17. A device as recited in claim 13 wherein said heat sink  
includes a material selected from the group consisting of  
include copper, aluminum, silicon carbide, boron nitride  
natural diamond, monocrystalline diamond, polycrystalline  
diamond, polycrystalline diamond compacts, diamond  
deposited through chemical vapor deposition and diamond  
deposited through physical vapor deposition.

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